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Impact of Temporal SNR Variation on MIMO Channel Capacity in Urban Microcells

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Abstract— **Usually the capacity of multiple-input multiple-output (MIMO) wireless communication channels is evaluated under the assumption of fixed signal to noise (SNR) scenario. In this paper the impact of temporal SNR variation on capacity of MIMO wireless channels in urban microcells is considered. Results based on data measured in line of sight (LOS) and non line of sight (NLOS) propagation scenarios at 5.3 GHz carrier frequency are presented. It is noticed that while the temporal SNR variation has significant impact on the capacity of MIMO wireless channel in NLOS propagation scenario, the influence is less under LOS condition.**

Index Terms— **MIMO systems, Channel capacity, Temporal SNR variation.**

I. Introduction

Multiple-input multiple-output (MIMO) wireless communication systems promise significant advantages over traditional single antenna systems [1][2]. However, parameters such as propagation environment [3], antenna array configuration [4] and antenna element properties [5] affect the promised advantages significantly. These parameters influence both the MIMO channel correlation properties and the target average receive signal to noise ratio (SNR). In MIMO systems performance investigation the usual concern is to study how changes in spatial correlation properties affect MIMO systems performance under the assumption of fixed SNR, e.g. [6]. In reality, this approach may slightly lead to misleading conclusions. For instance, the common understanding that the presence of a strong multipath component results in significant loss in MIMO channel capacity, relative to the case when this strong component is absent, is only true when we deal with normalized channel matrix. When SNR variation is taken into account different conclusion could be reached.

The impact of SNR variation on MIMO systems performance is not largely addressed in literature. However, channel capacity variation of indoor MIMO wireless channel was presented in [7] where it is noticed that the SNR variation has a greater impact on the channel capacity more than the channel correlation properties. In this work we study the impact of temporal SNR variation on MIMO channel capacity based on data measured in urban microcellular environment at 5.3 GHz carrier frequency. The investigation is carried out by analyzing the channel capacity calculated under fixed and temporally varying SNR. Results from line of sight (LOS) and non line of sight (NLOS) propagation scenarios are presented.

The rest of this paper is organized as follows: system model and employed signaling scheme is described in Section II. Section III presents MIMO channel capacity calculations. Measurement campaign description is given in Section IV. Numerical results based on the measurement data are presented in Section V. Our conclusion is drawn is Section VI.

II. System model and signaling scheme

Consider a narrowband MIMO wireless communication system with N_t transmit antennas and N_r receive antennas schematically shown in Figure 1. For high data rate applications the system employs spatial multiplexing scheme where different signals are transmitted from each transmit antenna. Since no channel knowledge in the transmitter side is assumed, equal power allocation strategy is employed in order to maximize the achievable channel capacity. Under this signaling scheme and power allocation strategy the input-output relation between the transmitted and received signals can be written as:

$$\mathbf{y} = \mathbf{G}\mathbf{x} + \mathbf{n} \tag{1}$$

where $\mathbf{y} \in C^{N_r,1}$ is the received signal vector, $\mathbf{x} \in C^{N_t,1}$ is the transmitted signal vector with covariance matrix $R_x = E\{\mathbf{x}\mathbf{x}^H\} = \frac{\sigma_x^2}{N_t}\mathbf{I}_{N_t}$, where $(.)^H$ denotes Hermitian transposition, σ_x^2 is the total transmitted signal power, $\mathbf{I}_N$ denotes identity matrix of size $N \times N$, $\mathbf{G} \in C^{N_r,N_t}$ is the narrowband measured channel matrix, $\mathbf{n} \in C^{N_r,1}$ is zero mean complex Gaussian receiver noise vector with covariance matrix $E\{\mathbf{n}\mathbf{n}^H\} = \sigma_n^2\mathbf{I}_{N_r}$ and σ_n^2 is the receiver noise power at each receive antenna.

It is usually more convenient to deal with the normalized version of the measured channel matrix. For this purpose we adopt the commonly used normalization technique that keeps the Frobenius norm of the normalized measured channel matrix to a fixed value [8]. This can be achieved by dividing the measured channel matrix by the normalization factor α as follows:

$$\mathbf{H} = \frac{1}{\alpha}\mathbf{G} \tag{2}$$

where α is given by:

$$\alpha = \sqrt{\frac{1}{N_t N_r} \parallel \mathbf{G} \parallel_F^2} \tag{3}$$

and $\parallel . \parallel_F$ denotes matrix Frobenius norm. With this normalization the spatial average power in the normalized channel matrix is set to one as follows:

$$\frac{1}{N_r N_t} \parallel \mathbf{H} \parallel_F^2 = 1 \tag{4}$$

The system model in (1) can be rewritten in terms of the normalized channel matrix as:

$$\mathbf{y} = \sqrt{\frac{\rho}{N_t}}\mathbf{H}\mathbf{x} + \mathbf{n} \tag{5}$$

where ρ is the temporal SNR that is defined as:

$$\rho = \frac{\sigma_x^2}{\sigma_n^2}\alpha^2 \tag{6}$$

III. Channel capacity

Channel capacity is a common performance measure of MIMO systems performance. It maps a channel realization to a non-negative scalar whose relative magnitude indicates channel quality. For the MIMO system model described in (5) the channel capacity can be written as:

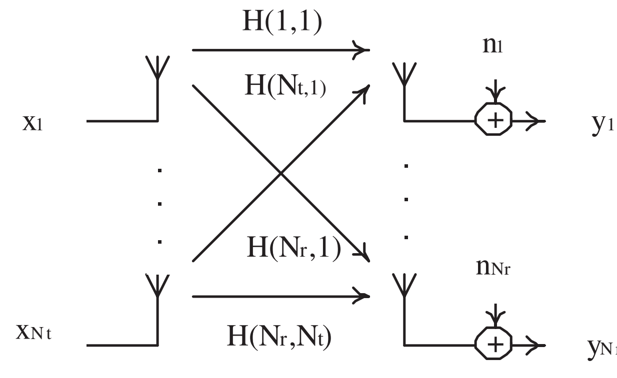

Fig. 1. MIMO System model.

$$c = \log_2 \det(\mathbf{I}_{N_r} + \frac{\rho}{N_t}\mathbf{H}\mathbf{H}^H) \quad b/s/Hz \tag{7}$$

When ρ is assumed fixed, channel capacity variations are due to changes in the channel correlation properties. Practically, fixed SNR implies that a perfect power control that compensates for the temporal SNR variation instantaneously is employed. In other words, it is assumed that the transmitter can track the SNR variation instantaneously and is capable of compensating for the required power. In reality, the transmitter has limited power and knowledge about the receiver SNR. Even when the power is not limited, practical issues such as power amplifier non linearity can limit the maximum transmitted power. Furthermore, instantaneous transmitted power update requires a feedback channel from the receiver to report the instantaneous SNR. The impact of temporal SNR variation on MIMO channel capacity is considered in this study based on measured data. In the following sections we briefly describe the measurement campaign and then analyze some numerical results.

IV. Measurement campaign

The measurement campaign was carried out at downtown of Helsinki at 5.3 GHz carrier frequency. The measurement campaign represents urban microcellular environment where a transmitter equipped with 16 elements dual-polarized planner antenna was located in the main street below the rooftops level at height of 10 m. A pseudo noise code with 60 MHz chip frequency was transmitted with power limited to 37 dBm [9]. A receiver equipped with 15 directive and dual-polarized semispherical antenna at height of 1.6 m was moved in different streets to create different routes. The receiver velocity was approximately 0.2 m/s and the channel transfer matrix was sampled at 14 Hz rate, meaning that between measurement of consecutive complex channel matrices the receiver was moved a distance of 0.014 m.

V. Numerical results

A. Propagation scenarios description

The results presented in the following subsections are based on subset of data taken from two measured traveling routes, NLOS and LOS. In the NLOS route the receiver terminal was moved in a street perpendicular to the main street with no line of sight component while in the LOS route the receiver terminal was moved in the main street where direct LOS component between the transmitter and receiver terminal exist. The propagation environment is shopping area with common glass structure in the first floor. In each route an appropriate subset of channel matrices with 4 transmit and 4 receive antennas along measurement route of 750λ is considered, where λ is the wavelength.

B. Temporal SNR variation

The temporal SNR ρ was calculated in both traveling routes as in (6) where the term σ_x^2/σ_n^2 was chosen in order to set the average temporal SNR to 20 dB. It was found that in order to achieve this SNR the ratio σ_x^2/σ_n^2 has to be set to 92 dB and 73 dB in NLOS and LOS traveling routes, respectively. One can observe that in order to achieve 20 dB temporal SNR the required transmitted power to noise ratio in NLOS route is 19 dB higher than that in the LOS route. This simply due to the nature of the NLOS propagation scenario where the received paths suffer from multiple reflections and diffractions compared to the direct path in the LOS propagation scenario. Histograms of the calculated SNR in both traveling routes are shown in Figures 2 and 3 for the NLOS and LOS traveling routes, respectively. It can be clearly seen that the 20 dB SNR is achievable very often in the LOS traveling route compared to the case in the NLOS route.

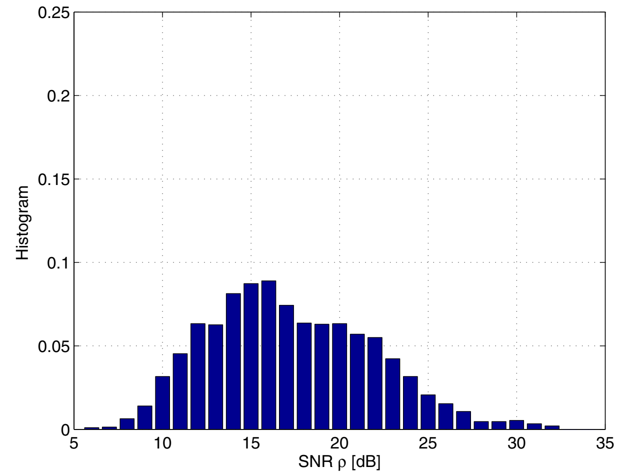

Fig. 2. Histogram of temporal SNR variations in NLOS traveling route with σ_x^2/σ_n^2=92 dB.

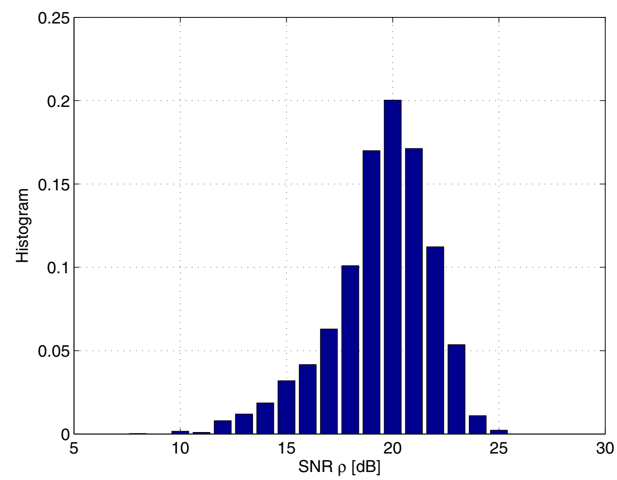

Fig. 3. Histogram of temporal SNR variations in LOS traveling route σ_x^2/σ_n^2=73 dB.

C. Impact on channel capacity

The channel capacities of both traveling routes were calculated in two cases, 1) with SNR fixed to 20 dB and 2) with using the SNR calculated in the previous section. The results are shown in Figures 4 and 5 in terms of the complementary cumulative distribution function (CCDF) for the NLOS and LOS traveling routes, respectively. The impact of temporal SNR variation in the capacity of the NLOS traveling route is evident. At 10% outage capacity the reduction in the channel capacity is about 35.71% relative to the fixed SNR case. In the LOS traveling route the reduction in the channel

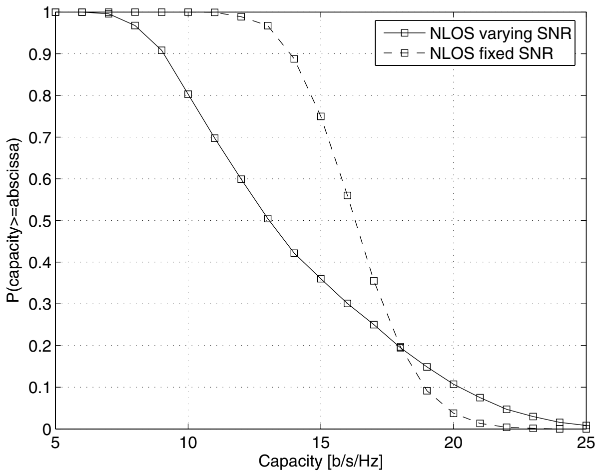

Fig. 4. CCDF of the measured channel capacity in NLOS route calculated with SNR fixed to 20 dB and temporally varying SNR.

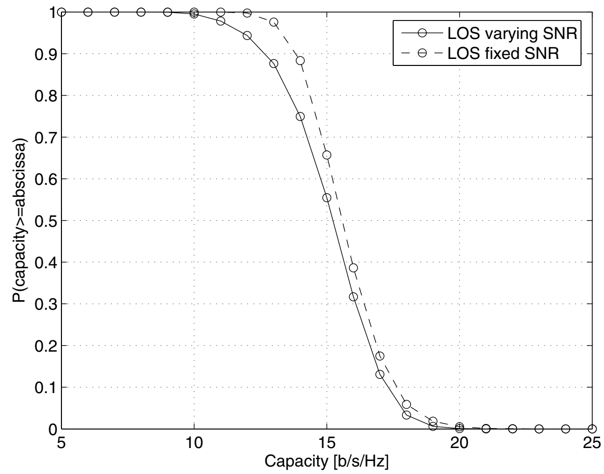

Fig. 5. CCDF of the measured channel capacity in LOS route calculated with SNR fixed to 20 dB and temporally varying SNR.

capacity relative to the fixed SNR case is about 7.14% at the same outage probability. Under fixed SNR the NLOS traveling route can offer higher capacity than the LOS route. However, when the temporal SNR variation is taken into consideration the LOS route offers channel capacity higher than the NLOS route although, the transmitted signal power to noise ratio used in the NLOS traveling route is 19 dB higher than that used in the LOS route.

One interesting observation is the slope of the CCDF of the channel capacity under the two SNR cases. Fixing the SNR changes the slope of the channel capacity significantly in the NLOS traveling route, while it is not in the LOS route. The slope of the channel capacity reveals useful information about the nature of the propagation scenario when temporal SNR variation is considered. Steeper slope reflects the existence of strong component that can maintain high and stable SNR. Smaller slope reflects large and fast fading of the available multipath components.

VI. CONCLUSIONS

We can conclude that under NLOS propagation conditions the impact of temporal SNR variation on MIMO channel capacity in urban microcells is significant. Perfect power control that can track and compensate receiver SNR variation is needed in order to enjoy the promised advantages of MIMO systems in NLOS propagation scenarios. Despite the undesirable correlation properties of the LOS propagation scenarios, they maintain relatively high and stable SNR.

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